Director, Operational Test and Evaluation

Lot 4 AH-64E Apache Attack Helicopter

Follow-on Operational Test and Evaluation Report

December 2014

This report on the Lot 4 AH-64E Apache Attack Helicopter fulfills the provisions of Title 10, United States Code, Sections 2399 and 2366. It assesses the adequacy of testing and the operational effectiveness, operational suitability, and survivability of the Lot 4 AH-64E Apache Attack Helicopter.

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Director

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Lot 4 AH-64E Apache Attack Helicopter

Executive Summary

This document reports on the evaluation of test adequacy, operational effectiveness, operational suitability, and survivability of the Lot 4 AH-64E Apache Attack Helicopter. The evaluation is based on data from the Follow-on Test and Evaluation I (FOT&E I) that was conducted by the Army Test and Evaluation Command from August 4 – 15, 2014, at Eglin Air Force Base, Florida, in accordance with a Director, Operational Test and Evaluation (DOT&E)-approved test plan. Following two years of developmental testing of new aircraft components, joint interoperability, cooperative cybersecurity, and live fire testing, FOT&E I included training, force-on-force missions in an operational Link 16 network, and adversarial cybersecurity testing.

As demonstrated in FOT&E I, Link 16 enhances the operational effectiveness of Lot 4 AH-64E units. Air Weapons Teams consisting of two aircrews equipped with two Lot 4 AH-64E aircraft found small target formations more quickly using Link 16 target tracks than when using their onboard sensors. AH-64E Air Weapons Teams equipped with Link 16 enhanced joint interoperability by providing battlefield information to the joint tactical air picture. With up to two hours on-station time, AH-64E Air Weapons Teams employ onboard sensors and their proximity to the battlefield to locate, identify, disrupt, and report enemy activity to joint forces. In scenarios with low target density, testing indicated Link 16 enabled aircrews to find an initial target more quickly than when using their onboard sensors; this effect was not observed in scenarios with high target density. (Ten targets or more was considered high density, less than 10 targets was low density.) The effect of Link 16 on the time to find initial targets in low battlefield densities may be optimistic because the target locations were generated in the lab from the actual coordinates of the target vehicles provided by the test instrumentation. In general, these target locations were significantly more accurate than an airborne sensor could provide. In addition, test results indicated overall mission success was not affected by the presence or absence of Link 16 targeting data or battlefield density of targets. Nonetheless, survey data indicate clearly aircrews viewed the ability to use Link 16 data favorably.

The Lot 4 AH-64E remains operationally suitable. It demonstrated sustained reliability with improvements in availability and maintainability compared to Lot 1 AH-64E operational test results. Transfer of in-flight maintenance data to the ground-based maintenance section was successful. The Systems-Level Embedded Diagnostics aided in aircraft recovery after mission completion.

The Lot 4 AH-64E remains as survivable as the Lot 1 AH-64E against ballistic threats. Survivability against infrared threats is degraded compared to the Lot 1 AH-64E. Infrared threat acquisition ranges are unchanged or increased and flare effectiveness is unchanged or decreased, depending on the threat and flight profile. Radar- and laser-warning systems degrade pilot situational awareness. Analyses based on material qualification ballistic testing confirm that the Lot 4 AH-64E meets requirements for ballistic survivability and force protection. Cybersecurity

testing found that a previously identified vulnerability had been corrected, but revealed new vulnerabilities for the Lot 4 AH-64E and its interfacing systems.

Mission Description and Concept of Employment

AH-64E-equipped units provide the Joint Force Commander and Ground Maneuver Commander the ability to defeat the enemy at a specified place and time. The Attack Reconnaissance Battalions assigned to the Combat Aviation Brigade employ the AH-64E to conduct attack, screen, reconnaissance, and security missions in land and maritime environments.

AH-64E helicopters are employed in Air Weapons Teams of two or more aircraft to conduct reconnaissance to locate and report enemy ground forces and limit or prevent enemy activity. AH-64E units conduct security operations by employing weapons to further locate and restrict enemy action, thereby providing reaction time, maneuver space, and protection for air or ground maneuver forces. AH-64E units employ their weapons in coordination with friendly ground forces to attack and destroy enemy forces.

System Description

The AH-64E, formerly known as the AH-64D Block III (AB3), is a modernized version of the AH-64D Attack Helicopter that will sustain the Apache fleet through the year 2040. AH-64E enhancements are planned in three major capability increments. The first capability increment (Lot 1) completed Initial Operational Test and Evaluation (IOT&E) in 2012. DOT&E reported the results of IOT&E testing in August, 2012 and assessed the system as operationally effective, operationally suitable, and survivable.

A second capability increment (Lot 4) completed operational and live fire testing in 2014, and the full capability (Lot 6) aircraft is scheduled for operational testing in March 2017. The major Lot 1 AH-64E capabilities included:

- Control of the payload and flight path of an Unmanned Aircraft System
- Improved aircraft performance with 701D engines, composite main rotor blades, and an improved rotor drive system
- Enhanced communication capability, including satellite communication and an integrated communication suite to meet global air traffic management requirements

Lot 4 AH-64E incorporates the Lot 1 capabilities and adds hardware and software for Link 16 network participation. Other Lot 4 AH-64E enhancements are described in the body of this report. The Army acquisition objective is to procure 690 AH-64E aircraft: 634 remanufactured and 56 new-build aircraft.

Operational Effectiveness

FOT&E I demonstrated that Link 16 enhances the operational effectiveness of Lot 4 AH-64E units. Air Weapons Teams found small target formations more quickly using Link 16 target

tracks than when using their onboard sensors. Large target formations with five or more vehicles were found just as quickly by onboard sensors as when using Link 16 targeting data.

Air Weapons Teams equipped with Link 16 enhanced joint interoperability. With up to two hours on-station time, Link 16-equipped AH-64E Air Weapons Teams used onboard sensors and their proximity to the battlefield to provide accurate and continuous updates on Link 16 target tracks. Lot 4 AH-64E Air Weapons Teams used their onboard sensors to locate and identify new targets on the battlefield and report those targets and their own locations on Link 16 to other joint network participants.

Lot 4 AH-64E aircrews used the Small Tactical Terminal Radio to participate in a joint Link 16 network with live and simulated Air Force fighters and command and control aircraft. The Small Tactical Terminal Radio experienced no critical or operational mission failures. All AH-64E sorties achieved Link 16 fine synchronization on every mission, maintained fine synchronization with the network 94 percent of the time, and demonstrated a 95 percent message completion rate.[1]

Lot 4 AH-64E enhancements and design changes add an average of 717 pounds as compared to the Lot 1 AH-64E. At this weight, nominally qualified engines with an engine torque factor of 1.0 do not produce enough torque to meet the out of ground hover Key Performance Parameter requirement. New engines for the AH-64E fleet are routinely fielded with an engine torque factor of 1.0 to 1.13. If permitted to use all available engine power, AH-64E has demonstrated in testing and in a recent unit in Afghanistan that the aircraft meets the hover Key Performance Parameter and has the ability to achieve operational performance requirements at 6,000 feet pressure altitude at 95 degrees Fahrenheit.

Operational Suitability

The Lot 4 AH-64E remains suitable. It demonstrated sustained reliability with improvements in availability and maintainability compared to Lot 1 AH-64E operational test results. Transfer of in-flight maintenance data to a ground-based maintenance section while the aircraft is on a mission was successful. The Systems-Level Embedded Diagnostics aided in aircraft recovery after mission completion.

Survivability

The Lot 4 AH-64E remains survivable. However, survivability against infrared threats is degraded compared to the Lot 1 AH-64E. Infrared threat acquisition ranges are unchanged or have increased, and flare effectiveness is unchanged or has decreased, depending on the threat and flight profile.

Radar- and laser-warning systems degrade pilot situational awareness. Threat-warning systems performed poorly and are poorly integrated. Pilots receive frequent and obvious false

[1] In a Link 16 network, each participating terminal must be in fine synchronization with the network time reference to within 7.8125 milliseconds to send and receive Link 16 messages. Terminals that fail to achieve fine synchronization are not allowed to transmit Link 16 messages on the network.

alarms, have no selective control of the warning systems, grow complacent even about accurate threat warnings, and have cluttered and conflicting threat displays.

The adversarial cybersecurity assessment found that a vulnerability of the Apache electronics architecture identified during the IOT&E in 2012 had been corrected, but identified new cybersecurity vulnerabilities on the Lot 4 AH-64E and its interfacing systems. Based on previous test results on different airframes, vulnerabilities in ground support equipment have created significant risk to aircraft embedded systems, including avionics, when they are connected to the airframe to transfer mission planning or logistics information. We do not know how significant these risks are for the AH-64E without further testing that allows a full assessment of embedded systems.

External fuel tanks meet ballistic material qualification self-sealing requirements and supported all FOT&E I missions. The external fuel tanks revealed no threat of sustained fire or catastrophic structural failures. The updated system-level vulnerability and force protection assessments for the Lot 4 AH-64E showed sustained ballistic protection of the aircraft and crew.

Recommendations

The Army should consider the following recommendations:

- Improve infrared countermeasure performance, upgrade radar- and laser-warning systems, and improve integration of aircraft survivability equipment on Lot 4 AH-64E aircraft.
- Address demonstrated cybersecurity vulnerabilities. Plan and conduct unconstrained exploitation of cybersecurity vulnerabilities of AH-64E and its ground support equipment during adversarial cybersecurity testing.
- Modify AH-64E performance charts and aircraft software to allow flight planning using actual engine performance ratings.
- Develop the capability to establish and maintain Link 16 networks for training of Lot 4 AH-64E units at fielding locations and at the National Training Centers.
- Continue development of Link 16 capabilities and conduct follow-on testing during FOT&E II.

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Director

Contents

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Section One
System Overview

The AH-64E, formerly known as the AH-64D Block III (AB3), is a modernized version of the AH-64D Attack Helicopter that will sustain the Apache fleet through the year 2040. AH-64E enhancements are planned in three major capability increments. This report addresses the second major capability increment, the Lot 4 AH-64E. Apache helicopters are employed in Air Weapons Teams of two or more aircraft to conduct attack and reconnaissance missions to locate, report, and destroy enemy forces.

Mission Description and Concept of Employment

Attack Reconnaissance Battalions are equipped with AH-64E helicopters and conduct reconnaissance, security, and attack missions in support of ground combat forces. AH-64E units conduct security operations by employing weapons to locate and restrict enemy action, to provide reaction time, maneuvering space, and protection for air or ground maneuver forces. AH-64E units employ their own weapons in coordination with friendly ground forces to attack and destroy enemy ground forces.

AH-64E units conduct attack missions in close proximity to friendly ground forces, attack enemy forces at distant locations, support helicopter assaults, and provide reconnaissance and security support day and night, over any terrain, and in adverse weather. AH-64E is designed to gain and employ situational awareness, move rapidly to positions of advantage, assimilate critical information, and deliver precision fires. To mitigate collateral damage and achieve optimal combat effectiveness, AH-64E units employ their own weapons or coordinate joint or artillery fires. AH-64E units establish and maintain connectivity with joint and ground forces through the use of airborne line of sight and satellite digital communications.

AH-64E crews employ onboard sensors to locate and engage targets. A nose-mounted sensor provides infrared and electro-optical video images to the pilot and co-pilot. This targeting and display system is integrated with lasers for ranging, locating, and designating targets for engagement. The optional mast-mounted Fire Control Radar employs millimeter radar to detect and classify moving and stationary vehicular and aircraft targets. Aircraft survivability equipment detects threat weapon signatures and provides cues to orient onboard sensors for targeting the threat.

AH-64E crews can be teamed with the Gray Eagle unmanned aircraft system to locate and engage enemy targets. By establishing a high-speed datalink with the unmanned aircraft system, AH-64E crews can receive video, locate and store target information using the infrared or electro-optical sensor aboard the unmanned system, employ the unmanned aircraft laser to designate targets for engagement, and reposition the unmanned aircraft.

Attack Reconnaissance Battalions can operate from established airfields and unimproved field sites. The battalion headquarters provides command and control, logistics, ammunition and fuel resupply, ground transportation, tents, and maintenance support necessary for sustained combat operations in any theater in the world.

System Description

The AH-64E is a modernized version of the AH-64D Attack Helicopter manufactured by Boeing. The legacy AH-64D Longbow Apache is a four-bladed, twin-engine attack helicopter with a tandem cockpit. The Longbow Apache entered production in 1995 and features a nose-mounted sensor suite for day and night target acquisition and an optional mast-mounted Fire Control Radar for target acquisition in dust, fog, and smoke. The AH-64D is armed with a 30 mm chain gun and carries a mixture of Hellfire missiles and 2.75-inch rockets. Legacy AH-64D Apache aircraft have double- and triple-redundant aircraft systems and armor shielding to provide survivability for the aircraft and crew.

AH-64E enhancements are planned in three major capability increments. The first capability increment (Lot 1) completed Initial Operational Test and Evaluation in 2012. A second capability increment (Lot 4) completed operational testing in 2014, and the full capability (Lot 6) aircraft is scheduled for operational testing in 2016. AH-64E will modernize the entire Apache fleet of 690 aircraft with the new capabilities listed in Figure 1-1.[2] Important features of the new Lot 4 capabilities are explained in more detail below.

FY 2012-2014 (91 Aircraft) AH-64E Lots 1-3	FY 2015-2016 (109 Aircraft) AH-64E Lot 4-5	FY 2017-2018 (491 Aircraft) AH-64E Lot 6
✓ Level IV unmanned aircraft system ✓ Improved communications suite ✓ Improved electronics / modular open systems approach ✓ Improved drive system ✓ Composite main rotor blades ✓ New fuselages ✓ Integrated aircraft survivability equiptment ✓ Signal processor unit ✓ Radar electronics unit ✓ 701D Engines with enhanced electronic control	✓ System level embedded diagnostics ✓ Link 16 (small tactical terminal) ✓ External fuel systems ✓ Air-to-air-to-ground ✓ Aircraft survivability product improvement ✓ Modernized tactical acquisition designation sight software version 8 ✓ Image Intensifier Television mode for pilot night vision system	○ Radar frequency interferometer passive ranging, and frequency range extension ○ Fire control radar range extension ○ Interactive electronic manual upgrade ○ Cognitive decision aiding system ○ Aided target detection and classification ○ Radar maritime mode ○ Image fusion ○ Day-side electro-optical sensor
Lot 1 tested in IOT&E March 2012	**Lot 4 tested in FOT&E I August 2014**	**Lot 6 to be tested in FOT&E II FY 2016**

Figure 1-1. AH-64E Lot 1 through Lot 6 Capabilities

Link 16

Link 16 is a tactical data network that assists the AH-64E aircrew with targeting and navigation, and enables communications and coordination with joint elements. The Lot 4 AH-64E Apache exchanges Link 16 data as a producer and consumer. The AH-64E produces Link 16 data automatically and uploads it to the network as it maneuvers, identifies, and engages enemy targets. Consumed information is displayed on the pilots' cockpit display and is updated

[2] Most (634) aircraft will be remanufactured: inducted from the current Apache fleet, disassembled, refurbished, modified, and reassembled with the redesigned AH-64E components. A small number (56) AH-64E aircraft will be built new to replace attrition aircraft and to create a new Apache battalion.

in real time as network participants, such as an E-8 Joint Surveillance Target Attack Radar System (J-STARS) or another AH-64E, gain new information. Link 16 data are exchanged using "J-messages" that follow a military standard format. The J-messages incorporated on the Lot 4 aircraft are tailored to its mission, and are shown in Figure 1-2.

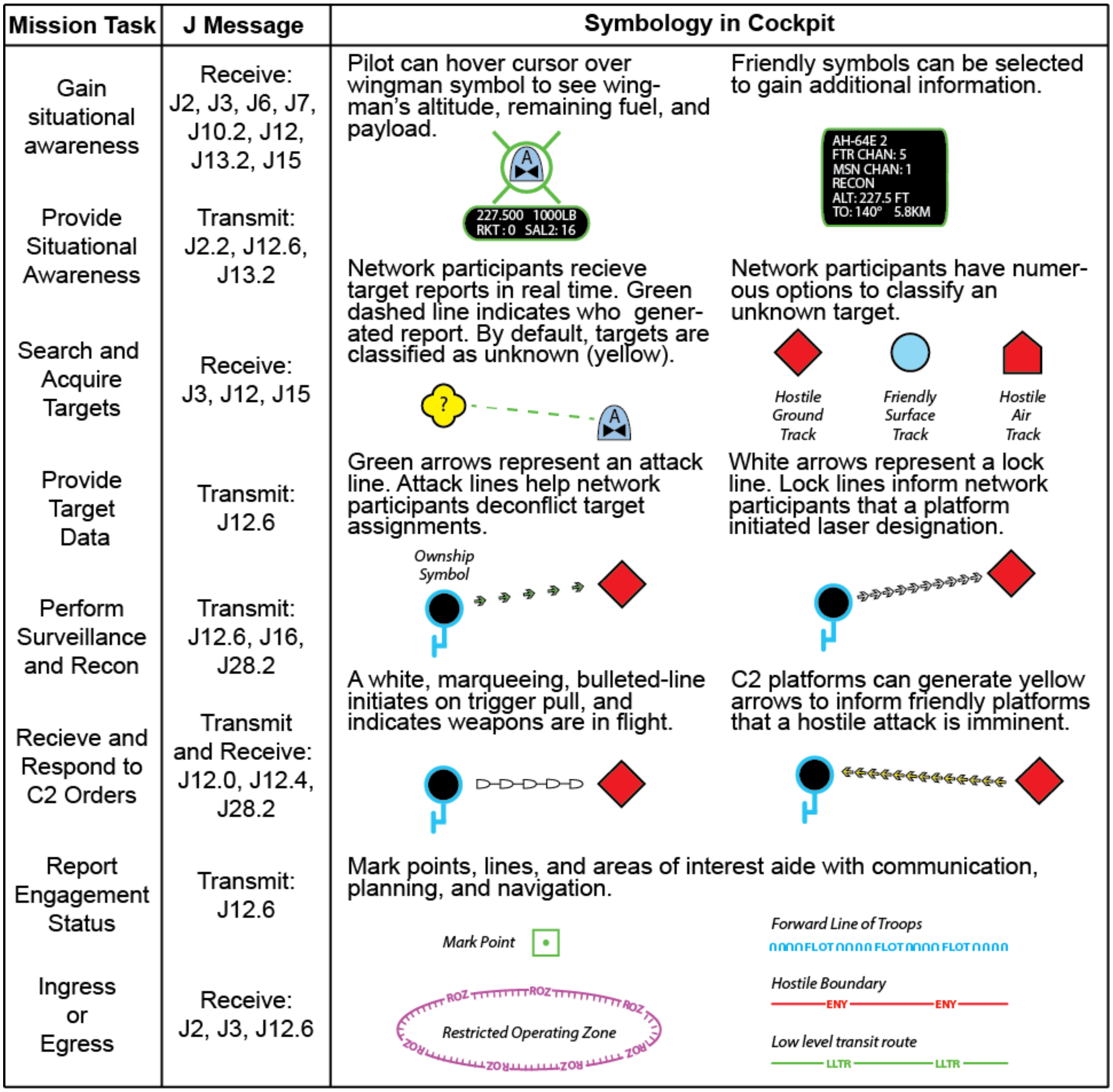


Figure 1-2. Examples of Link 16 Messages Available to Lot 4 AH-64E

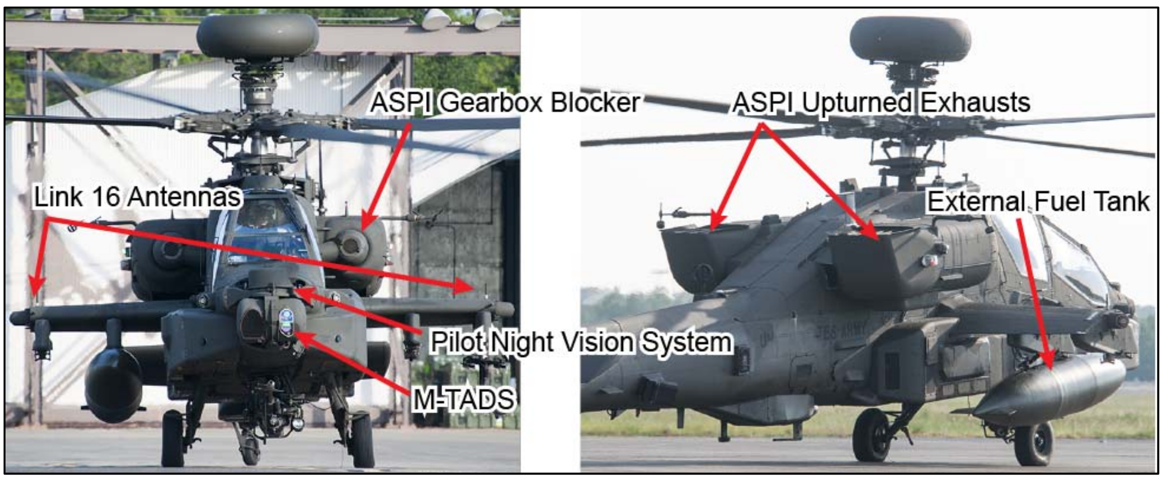
Boeing selected the ViaSat Harris Small Tactical Terminal Radio to implement Link 16 on AH-64E. It is "small" because of its size (9.5 pounds) compared to the Link 16 radio (42.5 pounds) that is used on larger fixed-wing aircraft. The Small Tactical Terminal is a dedicated radio for Link 16 that enables the AH-64E to join or independently establish a Link 16 network. The Army intends to replace the Small Tactical Terminal Radio interim materiel solution in Lot 6.

Air-to-Air-to-Ground

Air-to-Air-to-Ground (AAG) allows the AH-64E crew to exchange video from the nose-mounted sensor with a wingman or ground station. Video can be transferred in real time, or recorded and sent at a later time in flight. Real-time, inter-Apache video sharing provides awareness of a wingman's view, assists with target cueing, and, in a cluttered environment with complex targets, provides an additional perspective on a single target. Video transfer with a ground station can be used to share intelligence with Soldiers, or to receive positive identification of an enemy target and clearance to fire.

Reduced-size Crashworthy External Fuel System

The Reduced-size Crashworthy External Fuel System (RCEFS) is designed to extend the operational range of the AH-64E and to make refueling easier. Up to two 125-gallon external fuel tanks as shown in Figure 1-3 can be mounted on the inboard pylons and are crashworthy, self-sealing, and meet ballistic tolerance requirements. RCEFS installation includes new fuel lines, valves, controls, and a suction pump to enable automatic fuel transfer and defueling of selected internal and external fuel tanks.



ASPI – Aircraft Survivability Product Improvements; M-TADS – Modernized Target Acquisition Display Sight

Figure 1-3. Key New Features of the Lot 4 AH-64E

Sight Sensor Upgrades

The primary targeting sensor, the Modernized Target Acquisition Display Sight (M-TADS), is mounted on the nose of the aircraft and provides infrared and electro-optical video to the crew's cockpit displays. M-TADS software version 8 updates the automatic tracking modes. The new scene track mode keeps the sensor pointed at a fixed spot on the ground while point track mode fixes the sensor on a moving target. The auto-tracking modes are designed to reduce pilot workload.

The Image Intensifier Television (IITV) of the Pilot Night Vision System (PNVS) improves the pilot's ability to see light sources and avoid obstacles at night. The nighttime piloting sensor, the PNVS, transmits Forward-Looking Infrared (FLIR) images to the pilot's

helmet-mounted display. The Apache helmet tracking system orients the PNVS sensor with the pilot's line of sight to provide hands-free vision at night. The new IITV mode can be merged with the PNVS image to add visible light sources such as city lights, tracer rounds, and vehicle headlights to the PNVS image. Visible light sources provide important cues that enhance pilot situational awareness.

System-Level Embedded Diagnostics (SLED)

The System-Level Embedded Diagnostics (SLED) enables in-flight transfer of maintenance data to a ground terminal. Previously, maintainers had to wait until the aircraft landed to download maintenance data from the aircraft. SLED data include fault indications, diagnostics, and aircraft status and is transmitted to the ground using Blue Force Tracker. SLED is intended to facilitate maintenance planning and fleet management. The Apache program manager provided a Blue Force Tracker receiver, laptop, and display to the AH-64E maintenance unit for FOT&E I because Apache units do not have the equipment to view SLED data.

Aircraft Survivability Product Improvements

Aircraft Survivability Product Improvements (ASPI) consist of multiple modifications designed to decrease the infrared signature of the aircraft. The upturned exhaust and shroud, shown in Figure 1-3, redirects the engine exhaust plume upwards, while other modifications block the line of sight between threat systems on the ground and hot spots on the aircraft.

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Section Two
Test Adequacy

Operational and live fire testing were adequate to assess the operational effectiveness, operational suitability, and survivability of the Lot 4 AH-64E Apache Attack Helicopter. The Army Test and Evaluation Command conducted Follow-on-Test and Evaluation I (FOT&E I) from August 4 – 15, 2014 in accordance with a DOT&E-approved test plan. The test included training, force-on-force missions in an operational Link 16 network, and adversarial cybersecurity testing. It was preceded by two years of developmental testing that included component qualification, joint interoperability, cybersecurity, and live fire testing.

Operational Testing

The Army Test and Evaluation Command conducted pre-test training and tactics development from July 21 through August 1, 2014, and FOT&E I from August 4 – 15, 2014, at Eglin Air Force Base, Florida. The test was conducted in accordance with the FOT&E I test plan approved by DOT&E on June 25, 2014.

The Army chose Eglin Air Force Base as the test location because it has an established Link 16 network. The Air Force manages the Link 16 network from the 46th Test Squadron Laboratory. The Gulf Common Network range extends 200 miles in all directions and operates 24 hours a day, 7 days a week. The network hosts F-15 and F-16 fighters, F-35 Joint Strike Fighters, Joint Surveillance Target Attack Radar Systems (J-STARS), and Airborne Early Warning and Control System (AWACS) aircraft. In addition to interacting with live aircraft, the 46th Test Squadron Laboratory simulates F-15 and F-16 fighter and J-STARS aircraft within the Link 16 network using representative flight hardware in the lab. The Gulf Common Network is a real-world operational network and provided an adequate environment in which to test the Link 16 capability of the Lot 4 AH-64E.

Eglin Air Force Base is on the Gulf Coast near the western end of Florida's panhandle. Temperatures ranged from 71 to 92 degrees Fahrenheit and humidity varied from 31 to 87 percent during the test. The terrain has scattered vegetation, and numerous inlets and rivers at sea level. The subtropical weather produced isolated, short-duration thunderstorms that postponed the execution of two FOT&E I missions.

The Army Test and Evaluation Command established a headquarters element at the Eglin Airfield to exercise control of the training and testing. The headquarters element provided mission orders to the Apache company commander who planned and conducted operations with the AH-64E crews and maintainers. The test headquarters established secure communications and a Blue Force Tracker network. All AH-64E missions began and ended at the main airfield at Eglin Air Force Base.

All Apache aircraft, ground vehicles, and crew-served weapons (machine guns, mortars, and man-portable air defense weapons) were instrumented for real-time casualty assessment during all missions. The instrumentation used laser or geometric pairing to adjudicate force-on-force engagements. The results of these adjudications were transmitted in near-real time to the

mission participants and test headquarters to provide awareness of mission progress. When a threat vehicle was killed, the real-time casualty assessment instrumentation notified the operator of a kill and automatically deployed smoke to provide a visual indication of a kill. Apache pilots received audible reports of near misses and kills against the aircraft.

The 46th Test Squadron at Eglin Air Force Base facilitated connectivity to a real-world Link 16 network with live and simulated aircraft. Simulated J-STARS ground tracks were based on a live feed from the real-time casualty assessment instrumentation for the threat systems. In addition to generating Link 16 ground tracks for the true location of the threat systems, the 46th Test Squadron generated and provided false tracks to the Apache crews to avoid giving them unrealistic perfect information. In post-mission reviews, Apache crews often reported the confusion and wasted time caused by the false targets.

The operational test was supported by a unit from the Army's 1st Brigade, 4th Infantry Division who acted as the opposing threat force. On land, the opposing force was equipped with Soviet ground vehicles, including light and heavy armor, troop transports, surface-to-air batteries, and mobile rocket artillery. In maritime missions, the opposing force employed small, fast attack craft and a 40-foot mine laying boat. Man-portable infrared missile simulators, capable of stimulating the AH-64E Common Missile Warning System, were employed by the opposing force in 18 of the 22 missions. In five missions, actual threat radar systems were employed with simulated radar-guided missile launches against detected Apache aircraft. The threat forces used camouflage and deception to avoid detection and employed their weapons to engage and kill the Apaches whenever possible. On two occasions during the test, an AH-64E was adjudicated as killed by man-portable air defense systems.

During the conduct of each mission, the data collectors recorded significant events and weather conditions. Upon completion of each mission, aircrews, commanders, and soldier maintainers completed post-mission, after-action reviews and questionnaires. The Army recorded cockpit video and audio, selected aircraft state data, Link 16 messages, and real-time casualty assessment data. Throughout training and testing, data collectors recorded all AH-64E reliability failures and maintenance actions. All textual and quantitative data were consolidated into digital files and reviewed by the Army evaluators, program manager representatives, Army user representatives, and DOT&E representatives for accuracy. Video files were recorded and reviewed to provide better understanding of what took place during each mission. At the end of the test, the Army evaluator met with representatives from the Program Office, Training and Doctrine Command, and DOT&E to review each mission and record mission success scores.

The 12 pilots from the 1st Attack Reconnaissance Battalion, 25th Infantry Division had experience that was representative of a typical unit. On average, each pilot had 675 combat flight hours and 1,154 non-combat flight hours of experience. The least experienced pilot had 80 total flight hours and no combat experience, and the most senior pilot had 1,750 combat and 3,635 non-combat flight hours. Before onsite FOT&E I flight training, the AH-64E crews completed classroom and simulator training at Boeing's plant in Mesa, Arizona.

Over the 4-week period of training and testing, 3 AH-64E aircraft flew 120.4 flight hours. The aircraft were configured with Fire Control Radars, aircraft survivability equipment, and

external fuel tanks. During FOT&E I, the 3 AH-64E aircraft conducted 22 missions under the conditions shown in Table 2-1. The conditions were selected using Design of Experiments methodology using the four factors in Table 2-2.

Table 2-1. Description of Factors and Levels

Factor	Levels	Description
Link 16 Targeting Data	Yes	Yes if a command and control aircraft or simulator provides Link 16 radar tracks to the AH-64E Air Weapons Team
	No	
Battlefield Density	Low	Up to 10 enemy targets in the objective area
	High	More than 10 enemy targets in the objective area
Light	Day	Light level for the duration of the mission
	Night	

The mission configurations were executed as planned and provided adequate power to test for the main effects and interactions on the response variable (time to find the initial target), as shown in Table 2-2.[3] To facilitate efficient test execution and flight safety, all night missions were conducted after the day missions had been completed.

Table 2-2. FOT&E I Mission Configurations as Executed – Planned Values are in Parenthesis

	Battlefield Density (A)	Low		High	
	Light (B)	Day	Night	Day	Night
Link 16 (C)	No	3 (3)	1 (1)	2 (3)	2 (4)
	Yes	6 (4)	2 (1)	3 (3)	3 (3)

A - Battlefield Density (low or high)

B - Time (day or night)

C - Link 16 Targeting Data (yes or no)

Factor	Power
A	0.78 (0.76)
B	0.78 (0.76)
C	0.80 (0.81)
A x **B**	0.80 (0.80)
A x **C**	0.80 (0.76)
B x **C**	0.78 (0.78)

Additional Testing and Analyses

In addition to FOT&E I, the Army conducted test activities to augment the Lot 4 AH-64E assessment.

- The ballistic testing of the Lot 4 AH-64E Reduced-size Crashworthy External Fuel System (RCEFS) was conducted by Robertson Fuel Systems and the Army Aviation Applied Technology Directorate at Fort Eustis, Virginia, from March to May 2013 in accordance with military specification MIL-DTL-27422D, "Detail Specification for the Tank, Fuel, Crash-resistant, Ballistic-tolerant Aircraft." This specification covers

3 The power calculations assumed a signal-to-noise ratio of 1.0, an 80 percent confidence level, and that the time to find the initial target was continuous and normally distributed.

the requirements and verification testing for crash-resistant, ballistic-tolerant fuel cells for use in rotorcraft and tilt rotorcraft.

- The 46th Test Squadron conducted waveform conformance testing of the Small Tactical Terminal Radio, version 2.9.2 at Eglin Air Force Base in February 2014.
- The Joint Interoperability Test Command completed joint interoperability testing of the Small Tactical Terminal Radio version 3.1.2 at Mesa, Arizona, in May 2014. The AH-64E exchanged the required Lot 4 Link 16 messages with joint participants.
- The Army conducted a cooperative cybersecurity assessment of the Lot 4 AH-64E configuration from June 24 – 26, 2014, at Redstone Arsenal, Alabama.
- The Army Threat Systems Management Officer conducted an adversarial cybersecurity assessment from August 11 – 15, 2014. Concurrent with FOT&E I, the cybersecurity test team investigated deficiencies identified during the 2012 Initial Operational Test and Evaluation (IOT&E) and conducted passive scans of the AH-64E and associated networks.
- The Army Research Laboratory Survivability/Lethality Analysis Directorate (ARL/SLAD) completed system-level ballistic vulnerability and personnel protection analyses of the Lot 4 AH-64E with RCEFS and the latest armor configuration and provided a draft report in August 2014.
- The Army conducted infrared survivability testing in September 2014 at Redstone Arsenal, Alabama. The test compared threat seeker performance against the Lot 4 AH-64E equipped with ASPI to seeker performance against the Lot 4 AH-64E without ASPI.

Section Three
Operational Effectiveness

As demonstrated in FOT&E I, Link 16 enhances the operational effectiveness of Lot 4 AH-64E units. The AH-64E Air Weapons Teams equipped with Link 16 enhanced joint interoperability by providing battlefield information to the joint tactical air picture. The Air Weapons Teams found small target formations more quickly using Link 16 tracks than when using their onboard sensors. Air-to-Air-to-Ground (AAG) video transfer enhanced the Lot 4 AH-64E Air Weapons Team's situational awareness. The Image Intensifier Television (IITV) mode of the Pilot Night Vision System (PNVS) enhanced performance and improved the pilot's ability to detect light sources and avoid obstacles at night.

Lot 4 AH-64E enhancements and design changes add an average of 717 pounds as compared to the Lot 1 AH-64E. At this weight, nominally qualified engines with an engine torque factor of 1.0 do not produce enough torque to meet the hover Key Performance Parameter (KPP) requirement. The AH-64E fleet does not operate with nominal engines, but routinely operates with engines having engine torque factor ratings of 1.0 to 1.13. If permitted to use all available engine power, AH-64E has demonstrated in testing and in a unit's recent Afghanistan deployment that the aircraft has the ability to achieve operational performance requirements at 6,000 feet pressure altitude, 95 degrees Fahrenheit.

Mission Effectiveness

Mission Success

Lot 4 AH-64E Air Weapons Teams achieved complete or partial success scores on 16 of 22 FOT&E missions (73 percent). Mission success scores were assigned to the 22 missions by the scoring participants including the Army evaluator and representatives from the user, program manager, and DOT&E using the criteria in Table 3-1. These scores were assigned at the end of the test after reviewing recorded data of real-time casualty assessments, cockpit video, engagement and target acquisition video, post-mission debriefings, and mission logs. The scoring committee assigned mission success scores using the criteria in Table 3-1 that most closely described the mission events and mission outcomes.

As in the Initial Operational Test and Evaluation (IOT&E) of Lot 1 AH-64E, the mission success scores were not statistically responsive to the factors of interest in this test. By design, the mission success scores reflect the degree to which the mission outcomes achieved the commander's intent, in spite of the many uncontrolled factors, such as enemy actions, pilot decisions, and random events that influenced the mission outcomes.

Each mission followed one of four scenarios: Land Attack, Land Reconnaissance and Security, Maritime Reconnaissance and Security, and Screen for Unmanned Aircraft Systems (UAS). Prior to each mission, AH-64E crews were briefed on mission objectives, including the composition and last known location of enemy forces and high value targets. Aircrews generally attempted to engage targets outside the range of man-portable air defense systems (MANPADS) or small arms threats to ensure their own safety and survivability. When pilots strayed within

enemy engagement range during the FOT&E, the real-time engagement instrumentation allowed threat systems to engage and "kill" the Apache on two occasions when realistic threat engagement procedures were employed. The observed median engagement ranges against all threat systems during the FOT&E are shown in Figure 3-1. The Classified Annex to this report contains information on the measured threat MANPADS acquisition ranges and estimated vulnerability of the AH-64E to these threats at the engagement ranges observed during the FOT&E.

In the Land Attack Scenario, the AH-64E crew was tasked with neutralizing an enemy stronghold with a priority of eliminating high value targets. Opposing forces consisted of 17 enemy combatants, 5 tanks, 7 light armor vehicles, 3 MANPADS, 4 multiple launch rocket systems (high value target), and 2 radio frequency surface-to-air batteries (high value target). The enemy formation was tactically deployed within a 15-square kilometer opening that was surrounded by trees. Enemy target assets positioned themselves in the tree line or in the open to facilitate their mission task. Friendly forces consisted of the AH-64E Air Weapons Team and a simulated F-15 aircraft.

Table 3-1. Mission Scoring Criteria

Mission Score	Outcome	General Criteria
5	Complete Success	The Apache team quickly located and neutralized most or all of the threat systems, including all high value targets. Neither aircraft was destroyed. The team employed appropriate tactics.
4	Partial Success	The Apache team located and neutralized all high value targets. Neither aircraft was destroyed. The team accomplished most, but not all assigned mission tasks and employed appropriate tactics.
3	Neutral Outcome	The Apache team located and neutralized some high value targets. Aircraft were engaged, and possibly destroyed. The team accomplished some assigned mission tasks and employed inappropriate tactics at times.
2	Partial Failure	The Apache team located and attempted to engage some threat systems. One aircraft was destroyed. The team accomplished some assigned mission tasks and used inappropriate tactics.
1	Complete Failure	The Apache team was destroyed without locating or neutralizing any threats or high value targets. The team accomplished no assigned mission tasks and used inappropriate tactics.

The Air Weapons Team achieved complete success on all five Land Attack missions. The Air Weapons Team neutralized all high value targets and killed the majority of residual enemy forces. Using terrain masking, standoff, and nap-of-the-earth flight maneuvers, the Air Weapons Team avoided detection from surface-to-air threat systems and systematically located and neutralized enemy targets. The median engagement range against the ZSU-23-4, SA-6, and SA-8 surface-to-air systems, as shown in Figure 3-1, was greater than 5 kilometers. Link 16 radar tracks confirmed real-time threat locations as the aircrew maneuvered to and from battle

positions. The large target formation in this scenario facilitated finding the initial target, regardless of whether Link 16 targeting data were provided. After finding the first target, crews used onboard sensors to find additional targets. The Fire Control Radar and Radio Frequency Interferometer were used to locate hostile armor and surface-to-air vehicles.

In the Land Reconnaissance and Security Scenario, the Air Weapons Team escorted a convoy of three High Mobility Multi-purpose Wheeled Vehicles towards an enemy compound with the objective of neutralizing the compound and eliminating the high value combatant. Enemy forces included nine soldiers equipped with MANPADS, two mortars, four rocket-propelled grenade launchers, and four light vehicles. Link 16 was helpful in this scenario to locate initial targets and to maintain track of dispersing vehicles.

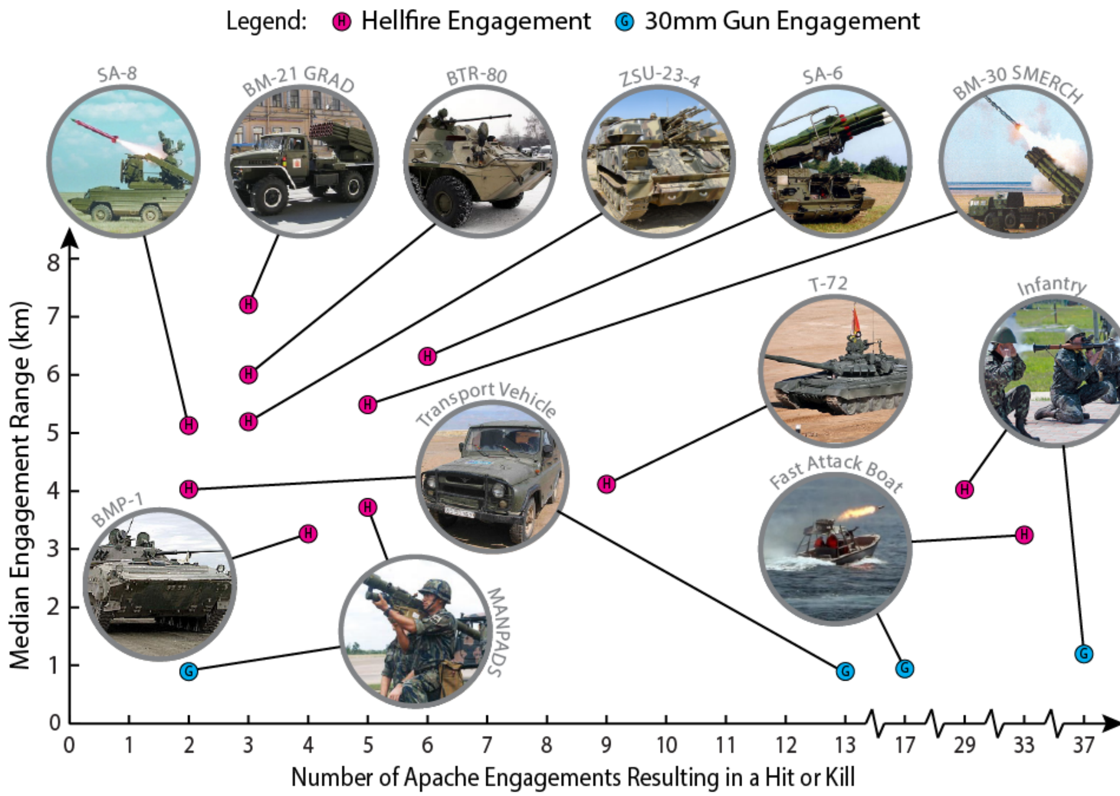

Figure 3-1. Summary of Apache Engagements during FOT&E I

AH-64E crews had an average mission success score of 3.7 on the six Land-Based Reconnaissance and Security missions. Without Link 16 targeting data to find the small dispersed target array, aircrews had difficulty finding the initial target. To the detriment of the crew's success, the enemy concealed themselves and their vehicles among non-combatants. In one successful mission, the aircrew followed an unmarked truck for more than 10 kilometers before the suspected high value combatant dismounted and began to setup a mortar tube. The aircrew shared AAG video of the suspected target with the tactical operations center, received permission to engage, and neutralized the target with the aircraft's 30 mm gun.

In the Maritime Scenarios, the Air Weapons Team mission was to secure a shipping lane by defending against a swarm of small attack boats or attacking hostile mine laying boats. The enemy boats were equipped with heavy machine guns, rocket-propelled grenades, and MANPADS.

The AH-64E crews performed well in the maritime scenarios with an average mission success score of 4.3 across eight missions. Link 16 helped with de-confliction of enemy target assignments as the fast attack boats swarmed toward a friendly transport vessel. AH-64E crews used Link 16 to broadcast the location of enemy mines to Link 16 participants. The Air Weapons Teams engaged threat boats at long range by manually tracking stationary and moving enemy boats with the laser designator for Hellfire missiles, or if at short range, with the 30 mm gun.

In the Screen for UAS scenario, the Air Weapons Team mission was to find an enemy UAS and either engage or provide targeting data to Link 16 for engagement by other aircraft. No ground forces participated in this scenario. Friendly forces consisted of the Air Weapons Team and a simulated F-15 aircraft. Enemy forces included the unarmed UAS.

The Air Weapons Team received two perfect mission success scores and one score of 2.5 in the UAS scenario. In the two successful missions, the aircrews used Link 16 to quickly locate the UAS in less than 2 minutes and hand over the target for a simulated F-15 engagement. In the unsuccessful mission, without Link 16 targeting data, the aircrew struggled to find the UAS despite receiving updated coordinates of its location from the tactical operations center. After 16 minutes, the aircrew eventually found the UAS, but a reliability failure in an aircraft mission processor forced the crew to abort the mission before reporting or engaging the unmanned aircraft.

In all missions, Hellfire and 30 mm gun kills were adjudicated by real-time casualty assessment instrumentation and verified by post-mission review of the cockpit video.

The analysis of all 22 missions indicates an average success rate of 4.16, with an 80 percent confidence interval of 3.86 to 4.46. Further analysis showed that mission success was not affected by Link 16 targeting data, battlefield density, light, or interactions between factors. The average mission scores and 80 percent confidence intervals are plotted in Figure 3-2 for each of the three test design factors. A p-value, the probability that the difference between levels is caused by chance alone, is shown for each factor and interaction.

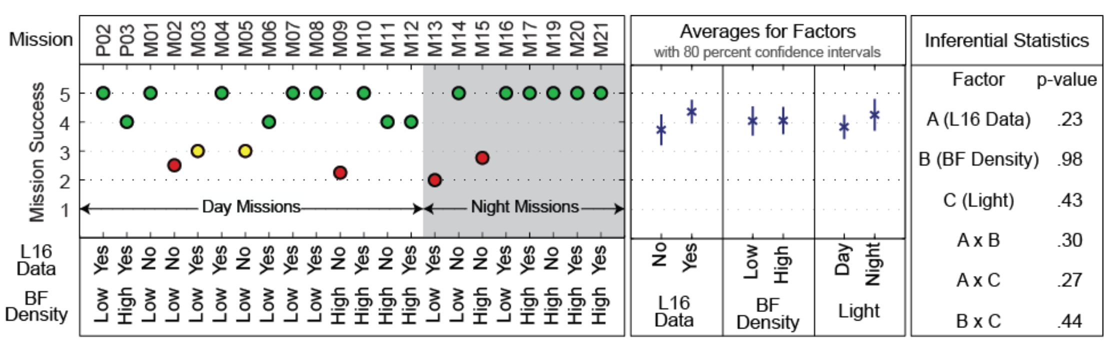

Figure 3-2. Data and Results for Mission Success

Link 16

AH-64E crews found initial targets more quickly using Link 16 target tracks than when using their onboard sensors. Army data collectors recorded the time to find the initial target for each of the 22 missions. The time to find the initial target was measured as the elapsed time between the reference starting point and the instant when the Apache crew put sensors on the first suspected target in the objective area. Reference starting points varied from mission to mission, but were consistent across test design factors to ensure unbiased comparisons of the time to find initial targets. Using data and video recorded during each mission, the Army evaluator, Army user representative, program manager representative, and DOT&E representative verified the starting point and the time the initial target was found for each mission. Battlefield density is included as a factor in the analysis below; 10 targets or more was considered high density, less than 10 targets was low density. However, the battlefield density numbers only include targets that had position location instrumentation, it did not include any of the live target tracks provided by the Gulf Coast network or the false/ghost tracks inserted by the test team.

Figure 3-3 indicates Link 16 targeting data helped AH-64E crews to find initial targets more quickly than when using their onboard sensors. On average across the 22 missions, large target formations were found more quickly than smaller target formations, regardless of whether Link 16 targeting information was available. The interaction between Link 16 targeting data and battlefield density was also significant and illustrates that : (1) Link 16 targeting data enabled the AH-64E crew to find small target formations more quickly than when using their onboard sensors (18 minutes faster); and (2) Link 16 targeting data had no effect on the crew's ability to find large target formations. Large target formations were easy to detect, whether Link 16 was available or not. The effect of Link 16 on the time to find initial targets in low battlefield densities may be optimistic because the target locations were generated in the lab from the actual coordinates of the target vehicles provided by the test instrumentation. In general, these target locations were significantly more accurate than an airborne sensor could provide.

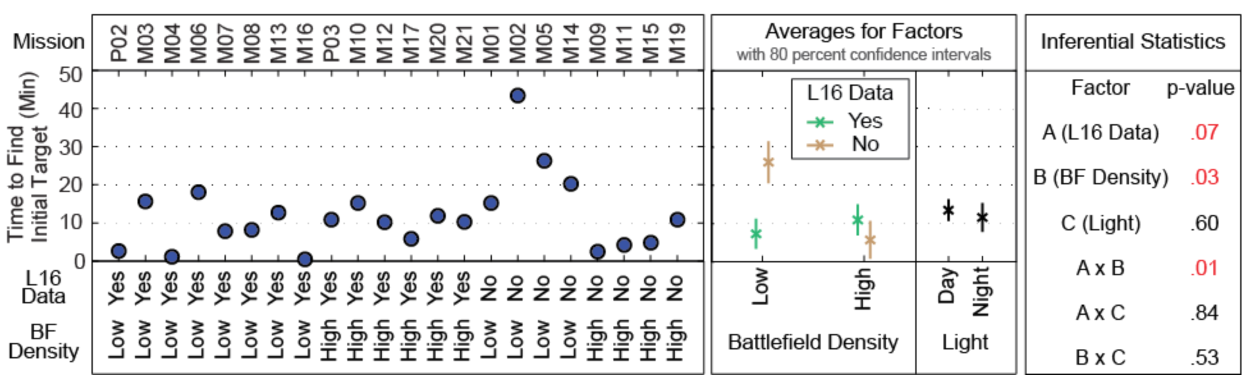

Figure 3-3. Data and Results for Time to Find Initial Target

Air Weapons Teams equipped with Link 16 enhanced joint interoperability. With up to two hours of on-station time, Link 16-equipped AH-64Es used onboard sensors and their proximity to the battlefield to provide accurate and continuous updates on Link 16 target tracks

to the joint tactical air picture. Lot 4 AH-64E Air Weapons Teams used their onboard sensors to locate and identify new targets on the battlefield and report those targets on Link 16 to other joint network participants.

Link 16-equipped AH-64E Apaches can be tracked by tactical air controllers more accurately using real-time Link 16 messages and as a result may be allowed to operate with fewer tactical airspace restrictions. Improved control could lead to reduced size and duration of restricted operating zones which allow aircraft to fly more direct routes to their objectives, reduce fuel burned, and increase on-station time for AH-64E aircraft.

Link 16-equipped AH-64E aircraft automatically share their location and activity with other members of the Air Weapons Team. As illustrated in Figure 1-2, Link 16 provides an icon for each AH-64E in the formation and provides activity indicators as to the ongoing actions of each aircraft. In this way, an Air Weapons Team can efficiently distribute targets for engagement among the members of the team and know in real time what each team member is doing.

Lot 4 AH-64E aircrews used the Small Tactical Terminal Radio to participate in a joint Link 16 network with live and simulated Air Force fighters and command and control aircraft. The Small Tactical Terminal Radio experienced no failures, achieved fine synchronization on every mission, maintained fine synchronization with a Link 16 network 94 percent of the time, and demonstrated a 95 percent message completion rate. Fine synchronization is necessary for AH-64E to be a full participant in the Link 16 network. The Mission 5 aircrews were required to form their own Link 16 network after entering the Air Force Link 16 network. The aircrew in aircraft 002 accomplished this successfully, but the aircrew in aircraft 009 was not able to accomplish the procedures for network formation, acquisition of the Network Time Reference, and subsequent reentry into the Air Force Link 16 network. Aircraft 015 did not participate in Mission 5. Figure 3-4 shows the duration of connectivity status during each FOT&E I mission.

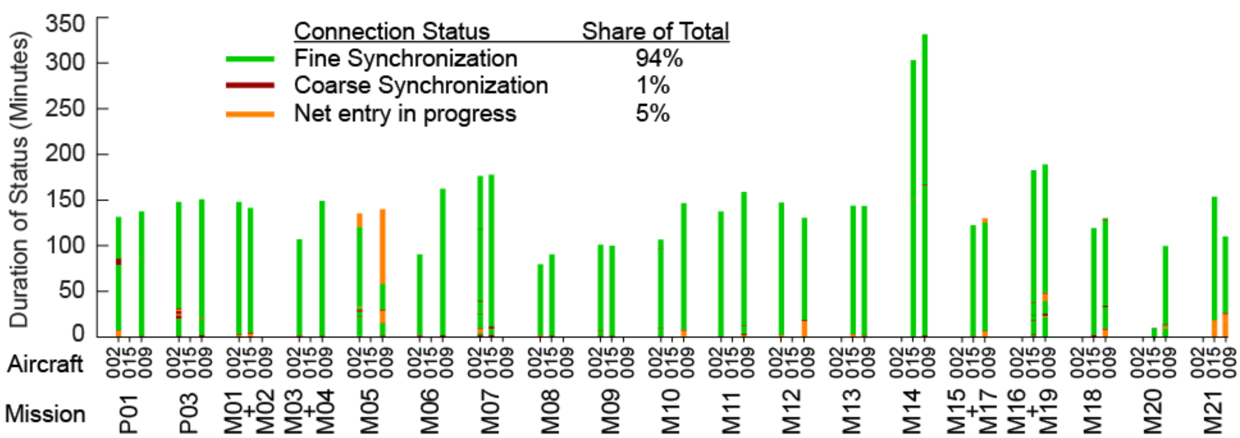

Figure 3-4. Summary of Link 16 Connectivity during FOT&E I

The FOT&E demonstrated that for AH-64E crews to develop and maintain proficiency in the effective use of Link 16, the Army will need to establish the capability to create or participate in Link 16 networks wherever AH-64E units are stationed or in training. While coordinating

with Eglin Air Force Base, Army testers were unable to find Army agencies responsible for Link 16 frequency and cryptographic management. Execution of the FOT&E was possible because the Air Force provided the infrastructure for a stable, active Link 16 network to support Apache participation. Consequently, as Lot 4 AH-64E aircraft are fielded, the Army will need to establish and maintain new Link 16 networks or tie in with existing Link 16 networks. The priority for this capability should be at the fielding locations of the Lot 4 AH-64E aircraft and at the Army's training centers (Fort Irwin, California, and Fort Polk, Louisiana).

Air-to-Air-to-Ground

Air-to-Air-to-Ground (AAG) video transfer enhanced the Lot 4 AH-64E Air Weapons Team's situational awareness. The aircrews transmitted video between aircraft in flight and to the maneuver operations center on the ground. Aircrews gave favorable feedback on the video quality and utility.

AAG was used extensively during FOT&E I to provide real-time Modernized Target Acquisition Display Sight (M-TADS) video streaming to a One System Remote Video Terminal (OSRVT) located at the headquarters element on the ground. The waveform and bit rate were configured to provide maximum range performance with the OSRVT. The maximum effective range was approximately 15 kilometers between the aircraft and the headquarters element when the OSRVT was equipped with an omni-directional antenna. The maximum effective range was approximately 50 kilometers when the OSRVT was equipped with a directional antenna capable of tracking the aircraft's location. AAG video was not received when the aircraft was out of range of the antennas or operating at low altitudes below the antenna line of sight.

Developmental testing indicated that the maximum range at which the AAG is able to transmit between two airborne AH-64Es using the Motion Picture Editor's Guild (MPEG)-2 file format is 17 kilometers and MPEG-4 is 35 kilometers[4]. This air-to-air range is sufficient for transmitting video and meta-data between two AH-64Es in an Air Weapons Team.

During FOT&E I, AH-64E gunners relied on AAG as an acquisition source to cue the M-TADS sensor. Figure 3-5 shows acquisition sources available to the gunner and frequency of use during the test. Preplanned targets were most commonly used, which included waypoints from mission planning as well as Link 16 radar tracks. AAG was the fifth most commonly selected acquisition source, representing 8 percent of the acquisition sources selected during the test. Pilots commented that the AAG acquisition source was the fastest way to see what their wingman was viewing.

[4] MPG-2 is intended to encode higher quality video and has file sizes (and therefore real-time transfer rates) several times as large as MPEG-4, which is intended to encode lower-quality video and loses more information in its compression algorithm.

Gunner Acquisition Source	Instances Used	Percent of Total
Preplanned Target	381	34
Gunner Helmet Site	234	21
Fixed Forward Position	232	21
Pilot Helmet Site	123	11
Air-to-Air-to-Ground	87	8
Aircraft Survivability Equipment	24	2
Radar Frequency Interferometer	21	2
Fire Control Radar	15	1

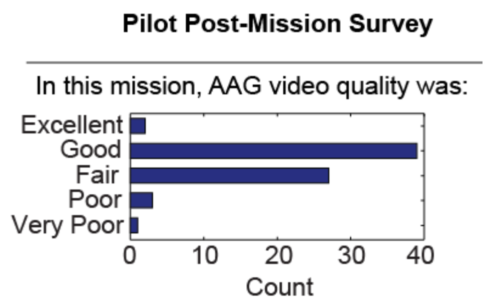

Figure 3-5. AAG use as an Acquisition Source and a Pilot Survey

Sensor Performance

Image Intensifier Television

The Electronic Image Intensifier Television (IITV) mode of the Pilot Night Vision System (PNVS) enhanced performance and improved the pilot's ability to see light sources and avoid obstacles at night. Figure 3-6 illustrates in the IITV image on the right that automobile and city lights are visible, features that are not visible in the Forward-Looking Infrared (FLIR) image of the same scene on the left. By having IITV images that are tracking the pilot's helmet and line of sight, pilots do not need to wear bulky night vision goggles that employ the same image intensifying technology.

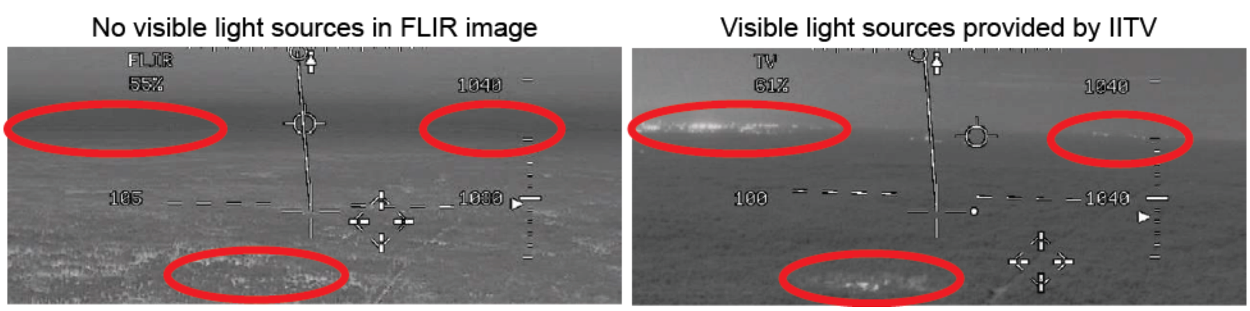

Figure 3-6. Comparison of FLIR and IITV Mode

PNVS was used during all night missions for a total of 21 hours. Out of the three PNVS modes available to the pilot, Figure 3-7 shows that the combined FLIR and IITV mode was most commonly used. For all FOT&E I night missions, FLIR mode, IITV mode, and combined mode were used 7, 6, and 87 percent of the time, respectively. Pilots reported that the new PNVS system was an improvement compared to the Lot 1 PNVS.

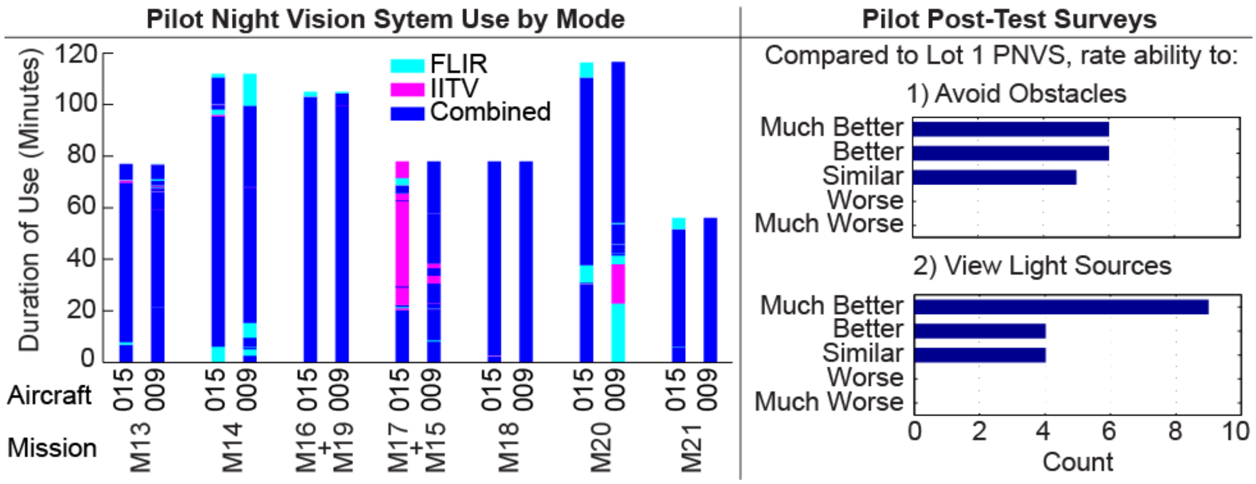

Figure 3-7. PNVS Usage and Pilot Survey Results

Modernized Tactical Acquisition Display Sight Software Version 8

At the urging of FOT&E test officers, pilots attempted to use the new version 8 auto-tracking features on 19 separate occasions. Each time, the tracker failed to track the target accurately enough to support a weapon engagement, whether using point or scene track mode. Instead, pilots used manual tracking for prosecution of all 30 mm gun and Hellfire engagements. M-TADS auto-tracking performance had no impact, good or bad, on engagement procedures or outcomes. Pilots reported that auto-tracker performance was no better or worse than legacy auto-track performance.

Results from developmental testing at Yuma Proving Ground, Arizona, between August 13 and September 26, 2013, reveal that M-TADS version 8 auto-tracking performs as well as or better than version 6.[5] In more than 60 Apache flight hours, auto-track was used in 622 instances against a variety of conditions. Results in Figure 3-8 indicate that version 8 had a higher probably of infrared sensor track for targets that were fully obscured (p-value = 0.12) or with the daytime sensor for targets obscured by natural surroundings (p-value = 0.01), while no statistically significant performance difference was noticed for other target conditions.

5 Modernized Target Acquisition Designation Sight / Modernized Pilot Night Vision Sensor Software Version 8.5 on the AH-64D Apache Helicopter, U.S. Army Yuma Proving Ground, January 27, 2014.

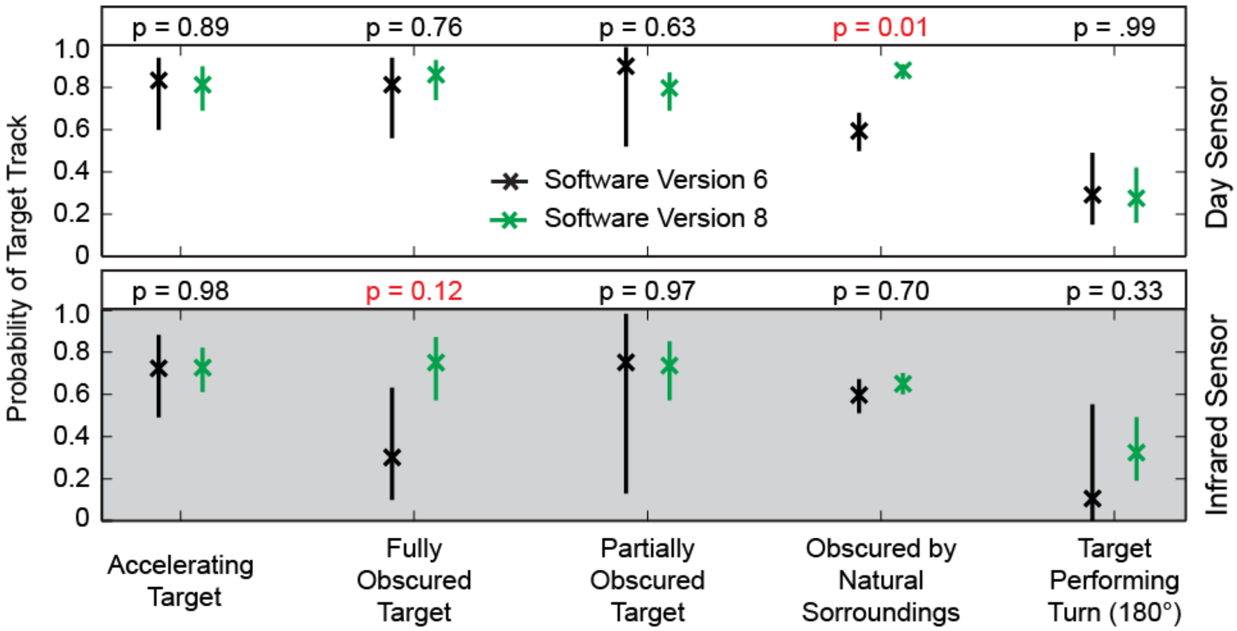

Figure 3-8. M-TADS Developmental Test Results

Aircraft Performance

By meeting the Key Performance Parameter (KPP) for hover out of ground effect, AH-64E aircraft can operate safely in mountains, such as in Afghanistan or Korea, with an operational load of ammunition and fuel. With new engines having an engine torque factor of 1.09 or higher, the Lot 4 aircraft meets the hover payload requirement of 3,320 pounds with a 3,366-pound payload at 6,000 feet pressure altitude and 95 degrees Fahrenheit. Figure 3-9 shows the hover payload of the Lot 4 aircraft.

Before new engines are installed on AH-64E, each engine is tested to determine its Engine Torque Factor (ETF) rating.[6] To meet contract specifications, a new engine must have an ETF of 1.0. The published AH-64E operator's manual estimates performance based on engines with an ETF of 1.0, and pilots normally plan missions anticipating the 717-pound shortfall in hover performance at KPP conditions. The Apache Program Manager reports that new engines are delivered with an average ETF of 1.09. This additional power is available for use in flight, but aircrew performance planning charts do not allow flight planning beyond an ETF of 1.0. While supporting Operation Enduring Freedom in 2014 in Afghanistan, the 1-229th Attack Reconnaissance Battalion reported that the engines on their ASPI equipped Lot 1 AH-64E aircraft had 8 to 10 percent additional power beyond predicted aircraft performance. The Army should consider revising the operator's performance planning charts to account for the actual engine torque factor (ETF) ratio, a rating that pilots confirm before and during flight. These updates will allow pilots to accurately calculate and plan for maximum fuel, ammunition, and single engine capability, and take advantage of all available engine power.

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6 Engine torque factor is defined as the ratio of individual torque available as compared to a specification engine at a reference temperature. A 1.0 value means the engine(s) will perform to or exceed a specified performance level.

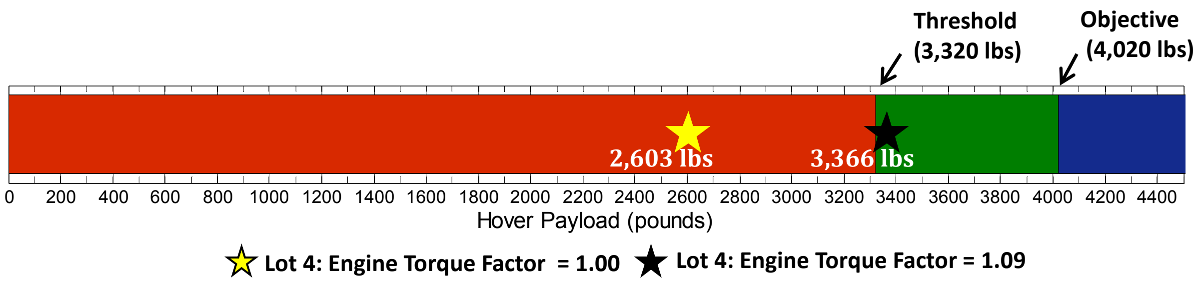
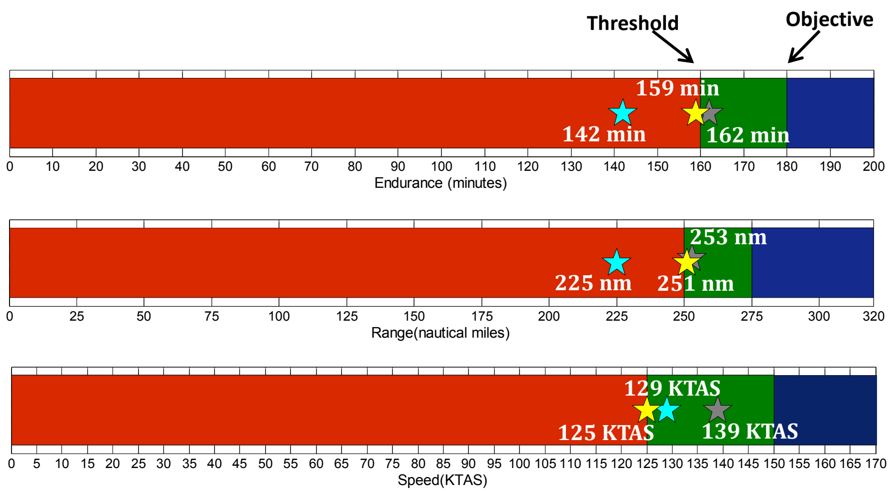


Figure 3-19. AH-64E Lot 4 Hover Payload Performance

Figure 3-10 illustrates the Lot 4 endurance, range, and dash speed performance at 6,000 feet pressure altitude, 95 degrees Fahrenheit. In each case, the Lot 4 aircraft meets the Key System Attribute requirements. The figure compares the Lot 4 aircraft to the Lot 1 aircraft performance. The Lot 1 aircraft meets the range and endurance requirements using the main fuel tanks, while the Lot 4 aircraft requires the auxiliary fuel tanks to meet the performance requirements. The degradation in aircraft performance is caused by the added weight of the Lot 4 upgrades, added weight of other Lot 4 design changes, and a reduction in engine power caused by engine backpressure with Aircraft Survivability Product Improvements (ASPI) installed.



Symbols for Speed	Symbols for Range and Endurance
☆ Lot 4 using Intermediate Rated Power (30 minutes) ☆ Lot 4 using Maximum Rated Power (10 min) ☆ Lot 1using Intermediate Rated Power	☆ Lot 4: main fuel tanks + auxiliary tanks ☆ Lot 4: main fuel tanks only ☆ Lot 1: main fuel tanks

KTAS – Knots True Airspeed

Figure 3-10. Key System Attribute Performance Requirements

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Section Four
Operational Suitability

The Lot 4 AH-64E remains operationally suitable. It demonstrated improvements in availability and maintainability compared to the Lot 1 AH-64E operational test results. Transfer of in-flight maintenance data to a ground-based maintenance section while the aircraft is on a mission was successful. The Systems-Level Embedded Diagnostics aided in aircraft recovery after mission completion.

Reliability

The Lot 4 AH-64E demonstrated mission reliability similar to fielded Lot 1 AH-64E aircraft and the mission reliability requirement. The Lot 4 aircraft did not meet the Key Performance Parameter for aborts with statistical confidence during FOT&E I. A mission failure that results in early termination or the inability to start a mission is a mission abort. The observed Key Performance Parameter for aborts, the Mean Time Between Mission Failure (MTBF(M)), is shown in Table 4-1 along with the 80 percent confidence interval and compared to results from Initial Operational Test and Evaluation (IOT&E) and for fielded Lot 1 AH-64E aircraft. Lot 4 FOT&E estimates for MTBF(M) are similar to earlier test and fielding estimates. Two FOT&E pre-flight aborts were induced by pilots who failed to wait 80 seconds before powering down the Auxiliary Power Unit as they were trained and as instructed by the operator's manual. Discounting these two pilot-induced failures, MTBM(F) during FOT&E I was 24.1 (13.0, 49.5) flights hours. None of the seven aborts that occurred during the 120.4-flight hour FOT&E suggest that the new Lot 4 components degrade mission reliability below that observed in fielded Lot 1 aircraft. The observed MTBF(M) point estimate of 17.2 hours supports a mission reliability estimate of 82 percent for a 3.5-hour mission reliability requirement of 80 percent.[7]

Table 4-1. AH-64E Lot 4 Reliability at FOT&E I[a]

		Demonstrated (80% Confidence Intervals)		
	Lot 4 Requirement	Lot 1 IOT&E	Fielded LOT 1	Lot 4 FOT&E I
Mean Time Between Mission Failure (MTBF(M)) (hours)	≥17.0[b]	36.7 (23.8, 59.0)	17.9 (15.9, 20.0)	17.2 (10.2, 30.9)
Mean Time Between Essential Mission Action (MTBEMA) (hours)	≥ 2.9[c]	4.9 (4.2, 5.7)	2.3 (2.3, 2.4)	3.9 (3.1, 5.0)
Mission Reliability	≥ 0.80	0.91 (0.86, 0.94)	0.82 (0.80, 0.84)	0.82 (0.71, 0.89)

[a] Based on 120.4 flight hours, 7 mission aborts, and 31 EMAs.
[b] Based on the Longbow Block I/II reliability requirement of 80 percent for a 3.5-hour mission.
[c] Based on a 20 percent improvement in the reliability of the Longbow Block I/II aircraft.

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[7] Mission reliability is the probability of completing a 3.5-hour mission without a single abort, assuming mission aborts are exponentially distributed with a mean of 17.2 hours.

As indicated in Table 4-1, the Lot 4 AH-64E performed better in FOT&E I than the required Key System Attribute threshold for Mean Time Between Essential Maintenance Actions (MTBEMA). An Essential Maintenance Action (EMA) is required following any incident or malfunction that results in the loss of one or more mission-essential functions. Once discovered, EMAs must be corrected before flight can resume. EMAs provide important insight about the reliability of mission-critical aircraft systems and components. During FOT&E I, half (15 of 31: 48 percent) of EMAs were caused by the avionics system. The drive system, electrical system, hydraulics, and landing gear accounted for an additional 35 percent of EMAs. The dominant failure modes observed in FOT&E I were similar to those observed in the fielded Lot 1 aircraft. Engine and transmission leaks continue in the AH-64E aircraft, with 3 of the 31 FOT&E EMAs (10 percent) caused by engine and transmission leaks. Field data indicate that about 4.5 percent of all EMAs are caused by engine and transmission leaks. While deployed, the 1-229th Attack Reconnaissance Battalion reported that the main transmission input seals, drive seals, and generator seals failed more often than legacy transmission seals.

Three EMAs affected Lot 4 upgrade components; two of those were pilot induced. During pilot training, one pilot was not able to load the Link 16 crypto keys. This failure did not re-occur during FOT&E I. One pilot reported that the Air-to-Air-to-Ground (AAG) was inoperative during pre-flight checks, but after mission completion, the AAG checked fine. On a different mission, pilots reported poor AAG video, resulting in the replacement of the AAG transmitter on one aircraft.

Maintainability

The Lot 4 aircraft did not impose an unusual maintenance burden on the FOT&E I unit and the Systems-Level Embedded Diagnostics (SLED) enhancement promises to reduce that burden in the future. To assess maintainability, two metrics estimate the effort required to keep the aircraft available for operations: unscheduled maintenance manhours per flight hour (MMH/FH) and mean time to repair (MTTR). Unscheduled maintenance manhours are those that result from correction of reliability failures. The aircraft met the unscheduled maintenance manhour threshold with confidence as shown in Table 4-2. The MTTR estimates the number of clock hours to return an aircraft to combat operations once a failure occurs. During FOT&E I, the Lot 4 AH-64E did not meet the MTTR requirement when calculated as a defined average. Since the average can be skewed substantially by a small number of outliers, a median time provides a better estimate than MTTR of the typical repair time. During FOT&E I, the median time to repair was 30 minutes

Table 4-2. AH-64E Maintainability at FOT&E I

		Demonstrated (80% confidence intervals)		
	Lot 4: Requirement	**Lot 1: IOT&E**	**LOT 1: Fielded**	**Lot 4: FOT&E I**
MMH/FH_{UNSCH}	≤3.4	1.1 hours	1.3 hours	0.5 hours (0.4, 0.7)
MTTR	≤1.5	4.3 hours	1.6 hours	1.5 hours (0.8, 2.7)
Median Time to Repair	N.A.	1.8 hours	N.A.	0.5 hours (0.4, 0.8)

Figure 4-1 shows the accumulation of unscheduled maintenance manhours during FOT&E I. There were four repair periods that account for 63 percent of unscheduled maintenance manhours. Each of these repair periods as described in Figure 4-1 required multiple diagnostic efforts to identify and eliminate the fault. The short times of the other repair periods illustrate that most repairs were accomplished quickly with one or two maintainers.

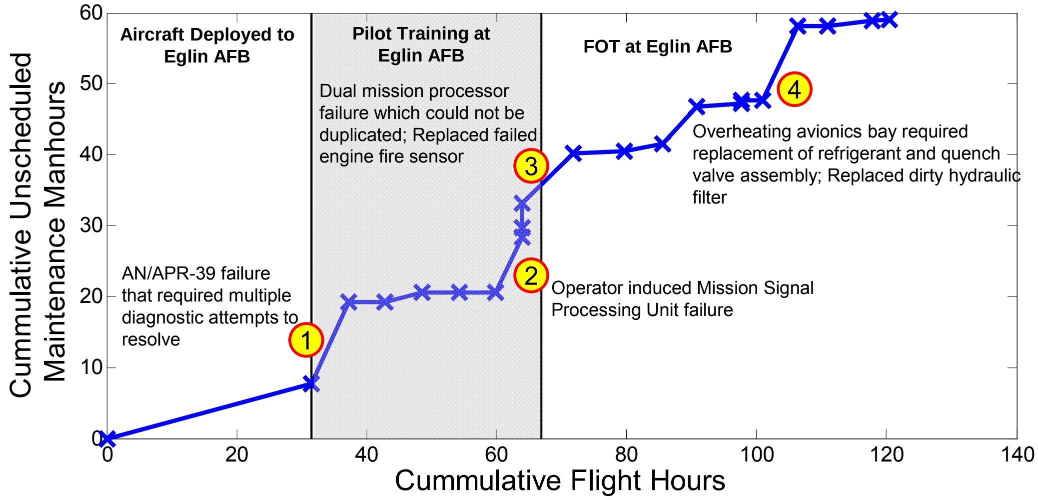


Figure 4-1. Cumulative Unscheduled Maintenance Manhours

As shown in Figure 4-2, 70 percent of the times to repair fell below 1.5 hours, and 50 percent fell below 30 minutes, making the median time to repair well below the requirement. The mean value of 1.5 was driven by two events that took longer than 6.0 hours to repair. These events were the faulty AN/APR-39 and the overheating avionics bay described in Figure 4-1.

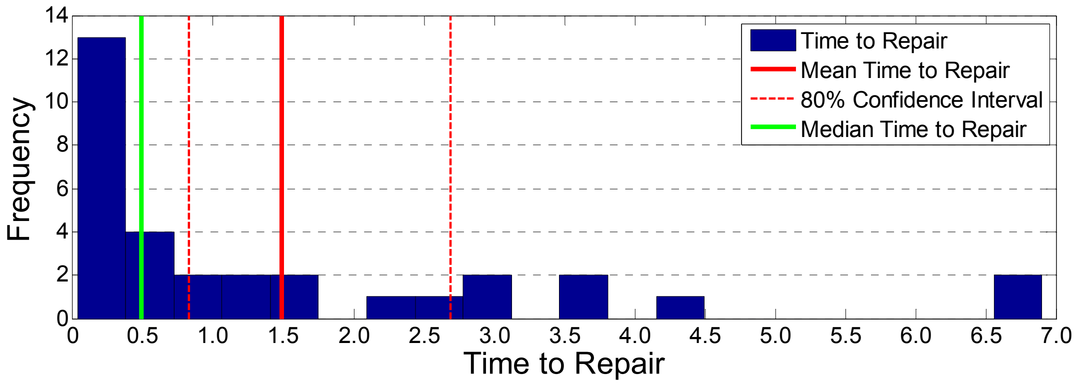


Figure 4-2. Distribution of Time to Repair during FOT&E I

Availability

During the follow-on operational test, the Lot 4 aircraft were available 87 percent of the time as shown in Table 4-3. The AH-64E aircraft does not have an availability threshold requirement. Aircraft availability measures the total time the aircraft is at least partially mission

capable, and is defined as the total uptime of the aircraft divided by the sum of the uptime and downtime.

At 4.8 hours, the average time of a downing event during the operational test was less than half a day, with three downtimes lasting 12 hours or more. Fifty-nine percent of all downtimes occurred on a single aircraft. This aircraft had an aircraft availability rate of 78 percent, while the other two aircraft had aircraft availability rates of 88 percent or more. The chart on the left of Figure 4-4 shows the downing periods for each aircraft, and highlights the downing events lasting more than 12 hours. Approximately 44 percent of the downtime was caused by logistic delay, 26 percent was caused by maintenance in progress, and 30 percent was caused by deferred maintenance for reasons other than logistics delays.

Table 4-3. Aircraft Availability

		Demonstrated (80% Confidence Intervals)	
	Lot 4: Requirement	**Lot 1: IOT&E**	**Lot 4: FOT&E**
Availability	N/A	0.76	0.87 (0.83, 0.92)

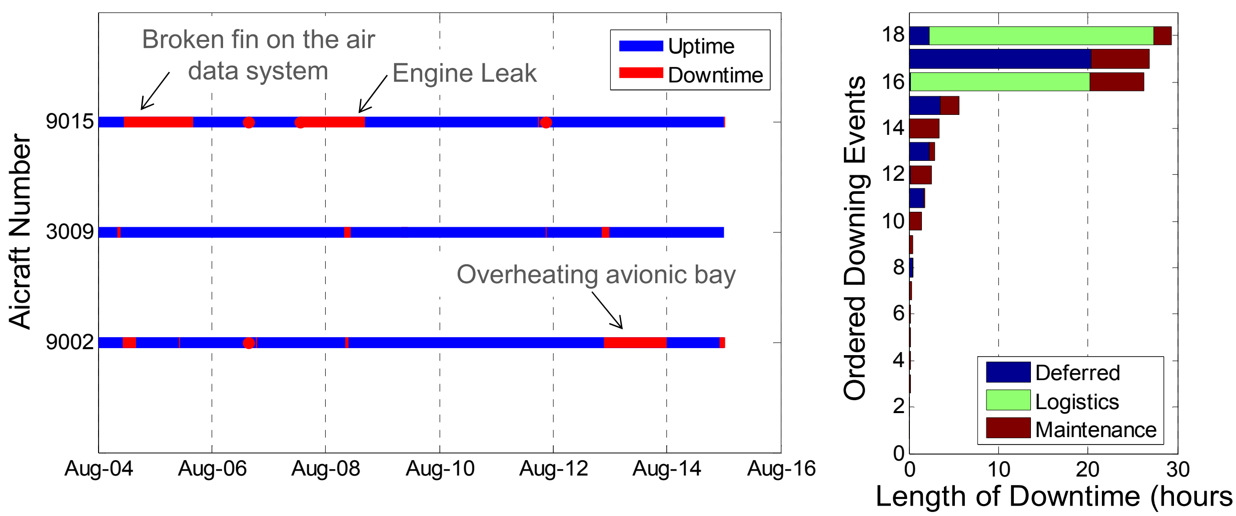


Figure 4-4. AH-64E Downtime during FOT&E I

Even though 44 percent of the downtime was caused by logistics delays, the unit did not have a systemic repair parts supply problem. The chart on the right in Figure 4-4 illustrates with green color that two downing events were responsible for all the logistic delay. In the first downing event, the FOT&E unit had to order a special tool to repair the fin and replace the sensor head on the helicopter air data system. The second event was associated with the overheating avionics bay, for which the unit had to order a quench valve and a refrigerant container. The third downtime, lasting more than 20 hours, was caused by an engine leak that required both a sump valve and engine seal replacement. After replacing the sump valve, the maintainers discovered the engine leak had returned after a few hours. The leak was finally patched by replacing an engine seal.

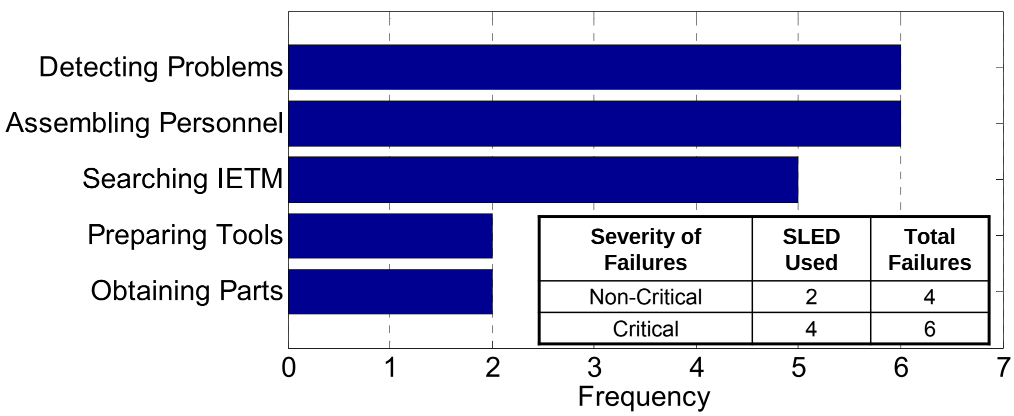
Operational Readiness

The Army's logistics readiness and sustainability guidelines cite a full mission capable goal of 75 percent for aircraft.[8] Two of the three FOT&E aircraft met this goal with 80 percent confidence. One aircraft did not meet this goal because of a faulty Radar Frequency Interferometer (RFI), which rendered the aircraft partially mission capable throughout the operational test. The RFI failure occurred at the start of the operational test. As the RFI was not essential to all missions for this aircraft, maintenance was deferred until after the operational test.

While supporting Operation Enduring Freedom in 2014 in Afghanistan, the 1-229th Attack Reconnaissance Battalion reported a full mission capable rate with Lot 1 AH-64E aircraft of 88 percent based on 11,000 flight hours.

System-Level Embedded Diagnostics

The Lot 4 follow-on test provided an early operational assessment of the SLED. Maintainers monitored the SLED during all missions, and acted upon SLED information in 6 of 10 inflight failures. Figure 4-5 shows that four of the six inflight failures were critical failures. Critical failures are those which negatively affect mission execution. Using the early detection capabilities of SLED, the maintainers were able to prepare the necessary tools and assemble personnel before the aircraft returned to base, as shown in Figure 4-5. The potential for early preparation was demonstrated in one mission in which a dual mission processor failure led to an abort. The maintenance crew received the SLED report and was waiting with tools in hand when the Lot 4 aircraft landed.



Severity of Failures	SLED Used	Total Failures
Non-Critical	2	4
Critical	4	6

IETM – Interactive Electronic Technical Manual

Figure 4-5. SLED Usage

Mission Workload

Mission workload was evaluated using the National Aeronautics and Space Administration (NASA) Task Load Index (TLX). The NASA TLX estimates the perceived workload of system operators performing system or mission tasks. Lot 4 pilots were asked to

8 Army Logistics Readiness and Sustainability, Army Regulation 700-138, Department of the Army, Washington, DC, February 26, 2004.

describe their workload in terms of the six dimensions described in Table 4-4. Operators' scores for each source were aggregated into an overall NASA TLX Index.[9] Figure 4-6 shows the NASA TLX scores for each pilot for each mission.

Table 4-4. Sources of Workload for NASA TLX

Temporal Demand How much time pressure did the pilot feel?	**Mental Demand** How much mental and perceptual activity was required?	**Effort** How hard did the pilot have to work to accomplish his level of performance?
Performance How successful did the pilot think he was in accomplishing the task?	**Frustration** How insecure, discouraged, irritated, and stressed did the pilot feel during the task?	**Physical Demand** How much physical activity was required?

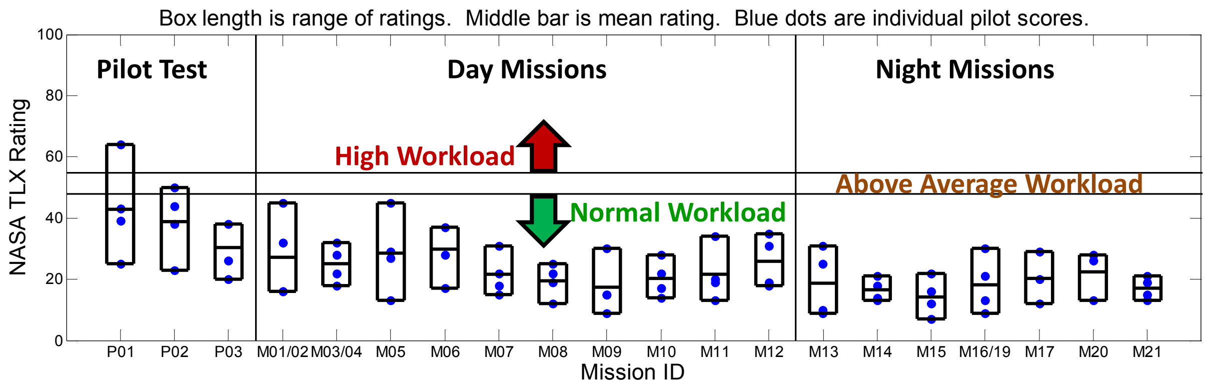


Figure 4-6. NASA TLX Scores for Each Mission

Overall, pilots indicated that workload was within a normal range for all missions except those in the pilot test. Higher workloads are to be expected in the pilot test because pilots are learning how to operate the new aircraft systems and incorporate them into the operational environment using new tactics and procedures. The influence of four factors, Link 16 targeting data (yes or no), battlefield density (low or high), light level (day or night), and pilot position (back seat or front seat), on mission workload was evaluated using a main effects and two factor interaction model. These results are shown in Figure 4-7.

Day missions had a statistically higher workload than night missions. To facilitate efficient test execution and flight safety, all night missions were conducted after the day missions had been completed. It is not clear whether the reduction in workload was caused by the change in light level or by pilot learning.

The presence of Link16 targeting data mattered for the front seat pilot. The back seat pilot flew the aircraft while the front seat pilot operated Link16. In high battlefield density environments, the front seat pilot had to decipher multiple targeting tracks, which increased

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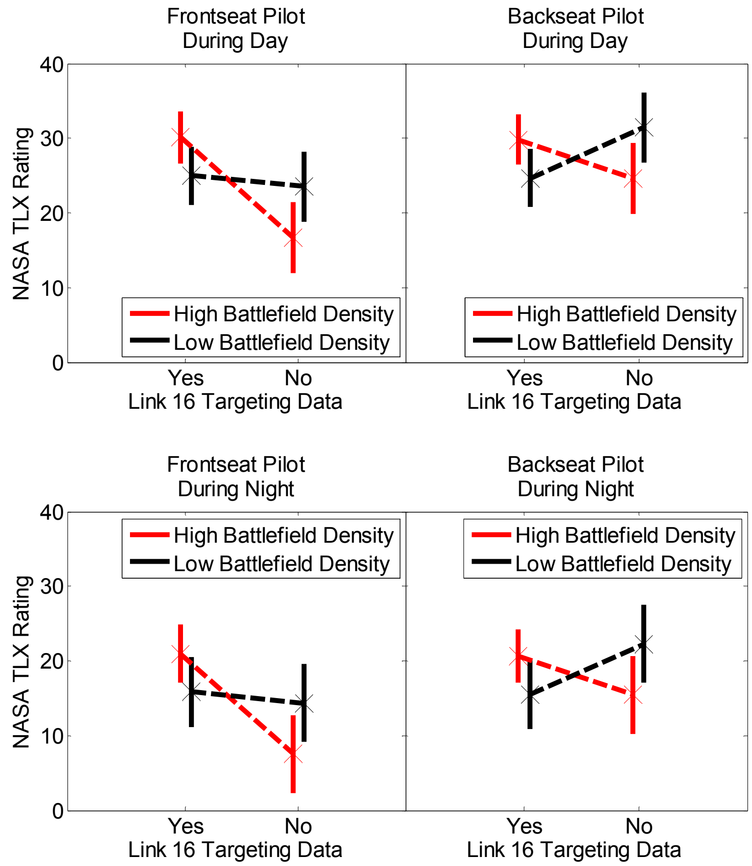
9 For a detailed description of the NASA TLX, see http://humansystems.arc.nasa.gov/groups/TLX/.

workload. In low battlefield density environments, pilots had few tracks to decipher, which allowed them to quickly identify threats.

Pilots reported two primary sources of workload across all conditions. Time pressure and the pilots' critical assessment of their own task performance were the dominant sources of workload. Slightly higher levels of frustration were reported when using Link16.



* 80 % confidence intervals shown
* 10% significance level used

Terms	p-value
Link 16 Targeting Data	0.22
Battlefield Density	0.76
Light Level	**0.001**
Pilot Seat Location	0.16
Targeting Data*Battlefield Density	**0.02**
Targeting Info*Light Level	0.73
Targeting Data*Pilot Location	**0.10**
Battlefield Density*Light Level	0.64
Battlefield Density*Pilot Location	0.39
Light Level*Pilot Location	0.33

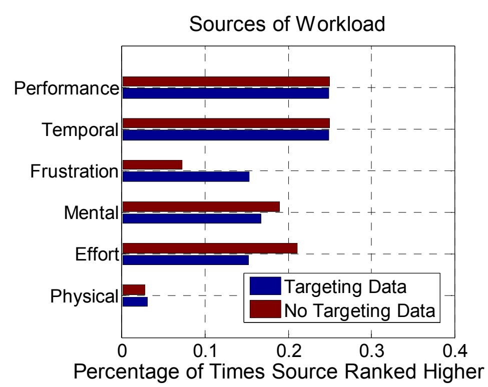


Figure 4-7. Mission Workload as Indicated by Pilots

The Army measured workload using the Bedford Workload Scale in addition to the NASA TLX. Pilots described their workload as low to moderate using the Bedford Scale. Unlike the NASA TLX, which showed a noticeable downward trend in workload as the operational test proceeded, the Bedford Scale showed no noticeable downward trend in workload level, as shown in Figure 4-8.

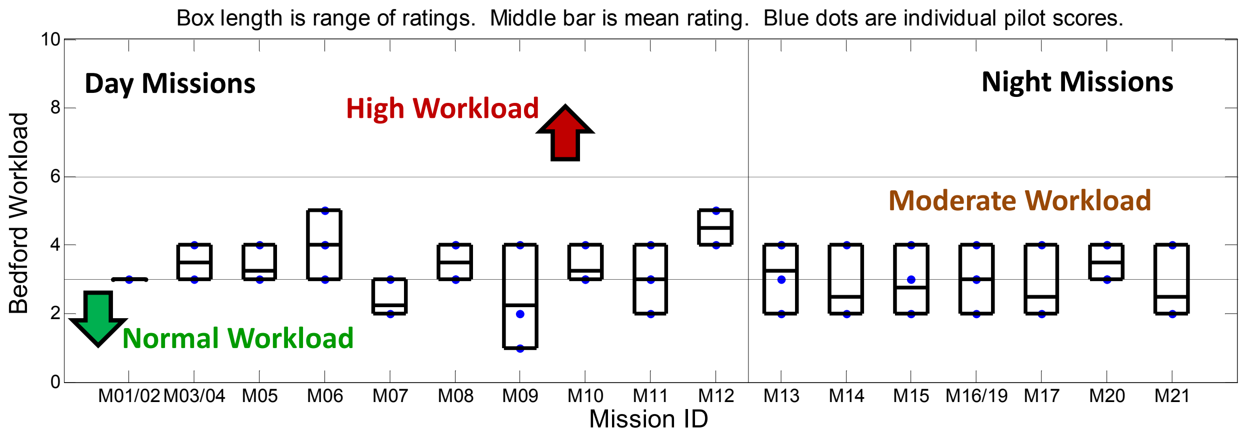


Figure 4-8. Bedford Workload Scores for Each Mission

The important factors and interactions identified by the NASA TLX and the Bedford workload scale were similar. These results are presented in Table 4-5. Both workload measures identified the light level and the interaction of targeting data and pilot location as statistically significant. The Bedford scale identified targeting data as statistically significant and the NASA TLX rating identified the interaction of targeting data and battlefield density as statistically significant. The Bedford Scale does not provide insight into the dominant sources of pilot workload.

Table 4-5. Comparison of NASA TLX Rating and Bedford Workload Scale

Terms	TLX	Bedford
	p-value	p-value
Link 16 Targeting Data	0.22	**0.05**
Battlefield Density	0.76	0.80
Light Level	**0.001**	**0.08**
Pilot Location	0.16	0.18
Targeting Data*[1] Battlefield Density	**0.02**	0.33
Targeting Data*Light Level	0.73	0.45
Targeting Data*Pilot Location	**0.10**	**0.05**
Battlefield Density*Light Level	0.64	0.58
Battlefield Density*Pilot Location	0.39	0.32
Light Level*Pilot Location	0.33	0.71

[1] * Indicates a 2-factor interaction.

Section Five
Survivability

The Lot 4 AH-64E remains as survivable as the Lot 1 AH-64E against ballistic threats. Survivability against infrared threats is degraded compared to the Lot 1 AH-64E. Infrared threat acquisition ranges are largely unchanged or have increased by the addition of the Aircraft Survivability Product Improvements (ASPI), and flare effectiveness is largely unchanged or has decreased, depending on the threat and flight profile.

Radar- and laser-warning systems degrade pilot situational awareness. Threat-warning systems performed poorly and are poorly integrated. Pilots receive frequent and obvious false alarms, have no selective control of the warning systems, grow complacent even about accurate threat warnings, and have cluttered and conflicting threat displays.

The new, smaller external fuel tanks meet the specified requirements for self-sealing after ballistic damage and supported all FOT&E I missions. The Reduced-size Crashworthy External Fuel System (RCEFS) revealed no susceptibility to sustained fire or catastrophic structural failure. The updated system-level vulnerability and force protection assessments for the Lot 4 AH-64E showed sustained ballistic protection of the aircraft and crew.

Table 5-1 compares DOT&E's 2012 assessment of the survivability and force protection Key Performance Parameters (KPPs) for the Lot 1 AH-64E with the results for the Lot 4 AH-64E. Additional details about AH-64E survivability results are in the classified annex.

The adversarial cybersecurity assessment found that a vulnerability of the Apache electronics architecture identified during the Initial Operational Test and Evaluation (IOT&E) in 2012 has been corrected, but identified new cybersecurity vulnerabilities on the Lot 4 AH-64E and its interfacing systems.

Table 5-1. Survivability and Force Protection KPPs

KPP	Measures	AH-64E Model	Assessment
KPP 4: Survivability	Ballistic Survivability	Lot 1	System-level vulnerable area slightly better than legacy AH-64D
		Lot 4	System-level vulnerable area of Lot 4 is unchanged from that of Lot 1 AH-64E aircraft Ballistic testing demonstrated the required self-sealing capability of external fuel tanks
	Infrared Survivability	Lot 1	Meets KPP for most Man-Portable Air Defense Systems (MANPADS) threats
		Lot 4	Meets KPP for most MANPADS threats, but infrared survivability is degraded compared to Lot 1
KPP 5: Force Protection	Crew armor protection, transparent armor	Lot 1	Exceeds or meets KPP: AH-664E crew armor protection exceeds KPP threshold. Transparent armor barrier in the cockpit meets the KPP threshold.
		Lot 4	

Countermeasure and Warning Systems

The Army conducted a comparison test between the AH-64E with ASPI and the AH-64E without ASPI installed to determine the net effects of the system on AH-64E against infrared-guided threats. In the first phase of this test, the Army measured threat seeker lock-on performance using 22 threat seekers representing 9 distinct threat capabilities against both aircraft configurations in a hover, level flight, and in a turn. In the second phase, the seekers attempted to continue tracking the aircraft following flare dispense, with the aircraft in a hover, level flight, and in a turn. In the third phase, the Army used a digital camera to record the long- and mid-wave infrared signature of aircraft in a hover and in level flight.

During FOT&E I, the opposing ground force employed threat-representative infrared man-portable air-defense systems and radar systems during mission execution. When Apache aircraft came within engagement range, the opposing ground force attempted to engage them. While the real-time casualty assessment instrumentation adjudicated the engagement, the threat weapons produced threat-representative infrared, ultraviolet, or radar signatures to stimulate the threat-warning systems on the AH-64E aircraft. Aboard the AH-64E, the AN/AAR-57 Common Missile Warning System generated audible warnings and a threat location icon when detecting simulated missile launches. The AN/APR-39 Radar Warning Receiver generated audible warnings and threat icons when detecting radar signals. The AN/APR-48 Interferometer generated threat icons on the Apache map, but generated no audible warnings. The AN/AVR-2B laser-warning receiver was integrated with the real-time casualty assessment instrumentation to assist with adjudication of engagements and was enabled to detect and generate aural and map-based icon warnings from actual laser designators and laser range-finders.

Infrared Susceptibility

Survivability of the Lot 4 AH-64E against infrared threats is degraded compared to the Lot 1 AH-64E. The installation of ASPI on the Lot 4 AH-64E had little positive effect on infrared threat seeker performance in most cases. For some infrared threats and flight profiles, threat acquisition range is increased (the Apache is less survivable), and flare effectiveness is decreased (again, the Apache is less survivable). Across the operational envelope, the net effect of installation of ASPI on the Lot 4 AH-64E is to reduce survivability against infrared-guided threat systems. The classified annex contains test results from the infrared testing.

Threat-Warning Systems

Radar- and laser-warning systems degrade pilot situational awareness. Threat-warning systems performed poorly and are poorly integrated. Pilots receive frequent and obvious false alarms, have no selective control of the warning systems, grow complacent even about accurate threat warnings, and have cluttered and conflicting threat displays. The classified annex contains test results from FOT&E I.

Ballistic Testing of Reduced-size Crashworthy External Fuel System (RCEFS)

The RCEFS fuel tanks meet the specified requirements for self-sealing after ballistic damage. Specifically, the entrance wound of the fuel bladders had a slow leak and achieved

damp seal in 2 minutes (less than 2 ounces of fuel leakage in 2 minutes) when shot with a tumbled .50 caliber Armor Piercing (AP) projectile. A single, higher caliber AP Incendiary (API) projectile test resulted in a damp seal. A single, high explosive incendiary (HEI) projectile test demonstrated tank structural integrity. The results of these tests were similar to those observed for the larger 200-gallon tanks tested during the UH-60M live fire test and evaluation. Overall, the RCEFS revealed no susceptibility to sustained fire or catastrophic structural failures, even when shot with the higher caliber projectiles.

Following the initial 13 tests performed in March, 2013 that revealed higher leakage rates (for some tests) than those specified, the original RCEFS tank design was modified to improve self-sealing performance by adding a backing board panel between the outer structural shell and the fuel bladder. The backing board helps maintain the flat surface of the structural wall, which improves damaged fuel cell self-sealing performance. A supplemental series of four tests performed on May 14, 2013, confirmed that the new design performed better.

Aircraft System-Level Vulnerability and Force Protection

The Army Research Laboratory Survivability/Lethality Analysis Directorate (ARL/SLAD) performed system-level ballistic vulnerability and personnel force protection analyses of the AH-64E Apache with RCEFS and latest armor using the well-known, widely used Army developed vulnerability assessment model. The analyses compared the Apache's Lot 4 configuration to the previous FY12 Apache Block III design. A draft analysis report was released for review in August 2014.

The system-level vulnerability analysis evaluated a variety of API and HEI projectiles, 51 grain fragments (from the AHEAD projectile), and rocket-propelled grenades[10] The analysis also estimated the aircraft vulnerability for low/slow (less than 100 feet/less than 40 knots) and high/fast (greater than 100 feet/80-120 knots) flight conditions. The differences in the analyses of the two aircraft configurations were minimal. Analyses confirmed that the addition of the RCEFS tanks and associated plumbing does not increase the AH-64E Apache's system-level ballistic vulnerability.

The personnel force protection analysis also indicated that the new level of protection for the single specified projectile threat did not reduce the ballistic protection to the pilot and co-pilot. A more detailed discussion of the results of the two analyses is presented in the classified annex.

Cybersecurity

The adversarial cybersecurity assessment found that a vulnerability of the Apache electronics architecture identified during the IOT&E in 2012 has been corrected, but identified new cybersecurity vulnerabilities on the Lot 4 AH-64E and its interfacing systems. The classified annex contains detailed cybersecurity findings and recommendations.

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[10] AHEAD: Advanced Hit-Efficiency and Destruction Round, a 35 mm projectile with 150 discs of 51-grain fragments.

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Section Six
Recommendations

The Army should consider the following recommendations:

- Improve infrared countermeasure performance, upgrade radar- and laser-warning systems, and improve integration of aircraft survivability equipment on Lot 4 AH-64E aircraft.
- Address demonstrated cybersecurity vulnerabilities. Plan and conduct unconstrained exploitation of cybersecurity vulnerabilities of AH-64E Apache and its ground support equipment during adversarial cybersecurity testing.
- Modify AH-64E performance charts and aircraft software to allow mission planning using actual engine performance ratings.
- Develop the capability to establish and maintain Link 16 networks for training of Lot 4 AH-64E units at fielding locations and at the National Training Centers.
- Continue development of Link 16 capabilities and conduct follow-on testing during FOT&E II.